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Interaction of Intense Electron Beams with Plasma

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Interaction of Intense Electron Beams with Plasma

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Abstract: An exploratory experiment has been performed on the propagation of intense relativistic electron beams through an ionized medium. The beam was produced on the Cornell facility and consisted of a 50 kAmp stream of 350 keV electrons. The initial plasma was produced by a conical theta pinch gun located 1.5 m downstream of the diode and it is estimated that the initial electron density at beam injection was about 10^{13} cm^{-3}. Beam propagation was observed photographically, on an X-ray diode at the end of the tube, and on magnetic loops along the tube. Results suggest that the bulk of the beam propagates down the tube at speeds of 1.8×10^8 m/sec. The magnetic probe signals indicate that there is appreciable counterstreaming current within the plasma volume.

Problem Status: This is a final report on an experiment which comprises one aspect of the study of intense relativistic beam propagation. It is expected that other more detailed experiments will be undertaken.

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Recent developments in the production of intense relativistic electron beams have opened up new areas of research on the interaction of beams with plasma[1]. The very large beam currents of relativistic electrons lead to very strong perturbations of the background plasma caused by the short duration pulsed fields set up by the primary beam. The scale lengths for such interactions are much smaller than beam-plasma particle collision lengths.

An exploratory experimental study of these interactions has been conducted to determine the propagation characteristics of the beam in a plasma background and compare this behavior with propagation in neutral gases[2]. In turn, these studies constitute the basis for planning beam-plasma interaction experiments with more intense electron beams, more uniform plasma, and an external magnetic guide field. Such experiments will permit quantitative comparison with theoretical models for beam propagation and interaction with a plasma background.

The electron beam used in this study was a 50 kA stream of 300 keV electrons produced by a diode driven by a Blumlein line. The behavior of the transmission line and diode has been discussed previously[3]. At injection into the plasma, the diameter of the beam is ~ 3 cm with a particle density of about 10^{12} cm^{-3}. The value of the parameter ν/γ * associated with such a beam is approximately 2.5. The electron beam in these experiments was injected into a 150 cm long, 10 cm i.d. drift tube, the inner wall of which was lined with a conducting screen. The tube was filled with plasma, generated by a conical theta pinch gun located at the far end of the tube from the diode. The discharge was produced in a pulse of 0.75 torr-liters of N_2 injected in the vicinity of the gun. A schematic of the experimental arrangement is shown in Fig. 1. The gun plasmoid rapidly moved down the evacuated tube ($p \simeq 1 \times 10^{-5}$ torr) and filled the volume near the diode with plasma. At the time of beam injection the plasma density was estimated to be of the order of 10^{13} cm^{-3} and the density of neutrals, not to exceed 2×10^{14} cm^{-3} near the diode. The mean free path of beam electrons for binary collisions is of the order of 50 meters at these densities.

To evaluate the propagation of the beam in the plasma, magnetic probes, photography and X-ray scintillators were used. Control experiments with beam injection into vacuum (10^{-5} torr) and into high pressure neutral gas (500 mtorr of N_2) were also performed.

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* The parameter ν/γ was introduced by Lawson[4] to classify beams according to their longitudinal-to-transverse energy partition.

When the beam was injected into the tube containing no background gas or plasma, no propagation of the beam occurred, as seen in Fig. 2a. It was found previously[2] that an increase of the gas pressure in the drift tube above 200 mtorr (7×10^{15} neutrals/cm^3) was necessary for beam propagation. Such propagation is seen in Fig. 2b. Finally, Fig. 2c shows an intense beam moving through the center of the plasma generated by the electrodeless discharge.

It is evident that the details of propagation must be different in the last two cases, since ionization of a high density background gas is no longer required for beam propagation when the beam is injected into plasma. There are two qualitative differences also apparent between these two cases as seen in the time-integrated photographs. First, the beam propagating into the plasma consistently appears to be narrower than the beam going into neutral gas. Second, the characteristic radial "feathery" structures that are typically seen between the beam and the return grid in the neutral gas case, were not observed when the beam propagated into plasma.

The beam current associated with the electron stream was measured by three single-turn loops placed just within the conducting grid at 15 cm, 65 cm and 115 cm down the drift tube from the injection point. The injected current was monitored by another probe measuring current within the diode. The three probes in the drift tube measure the net current which consists of the primary energetic particle beam less any backstreaming current induced in the plasma. Typical signals are shown in Fig. 3 for the case in which the beam is injected into plasma. When

the tube was evacuated (i.e. Fig. 2a) no signal was obtained on any of the drift tube probes. When the beam was injected into high pressure gas (Fig. 2b), signals similar to those in Fig. 3 were obtained, but the net current on all three probes was somewhat higher.

The probe signals were correlated in time to measure the beam front velocity. It was found that it propagates with a velocity of about 1.8×10^8 m/sec indicating that, at least the electrons in the beam front, move in straight trajectories. To substantiate the photographic evidence of large primary beam currents, a tantalum foil was placed at the end of the drift tube. Bremsstrahlung radiation generated by the primary beam striking the foil was used to determine that the primary beam energy propagating down the drift tube is indeed large. The X-ray pulse duration indicates that the remainder of the beam electrons also move in straight trajectories.

This experiment has shown that intense relativistic beams can propagate into a plasma whose particle density is lower by at least a factor of 10 then was possible in experiments where a neutral background gas was used. The beam diameter tends to be smaller and losses to the walls may be smaller. The large propagation lengths (1.5 m) indicates that scattering of the primary electrons by such collective processes as turbulent fields arising from two-stream instability are negligible, even though the time constant for growth of such fields is considerably shorter than the flow time of the beam past a point.

It is evident from Fig. 3 that the net current is much larger near the beam injection point. This is similar to results obtained with beam

propagation in the neutral gas[3]. The net current further along the drift tube is very small. Although the magnetic probes in the drift tube wall can not uniquely establish the partition of current between plasma and return current screen, the presence of the screen serves as a simulation of the infinite extent plasma, making it possible to relate this experiment to one of the models studied by Hammer[5]. The observation of very small net current is in qualitative agreement with that model where it is assummed that $n_p \gg n_b$.

In summary, this experiment has demonstrated that intense relativistic electron beams can propagate into low density plasma. Some qualitative understanding of the propagation has been achieved and the observations seem to agree with theory. It is hoped in the near future to make these findings more quantitative as well as to extend them to beams of higher values of ν/γ. The present experiment has proven valuable in suggesting directions for future work.

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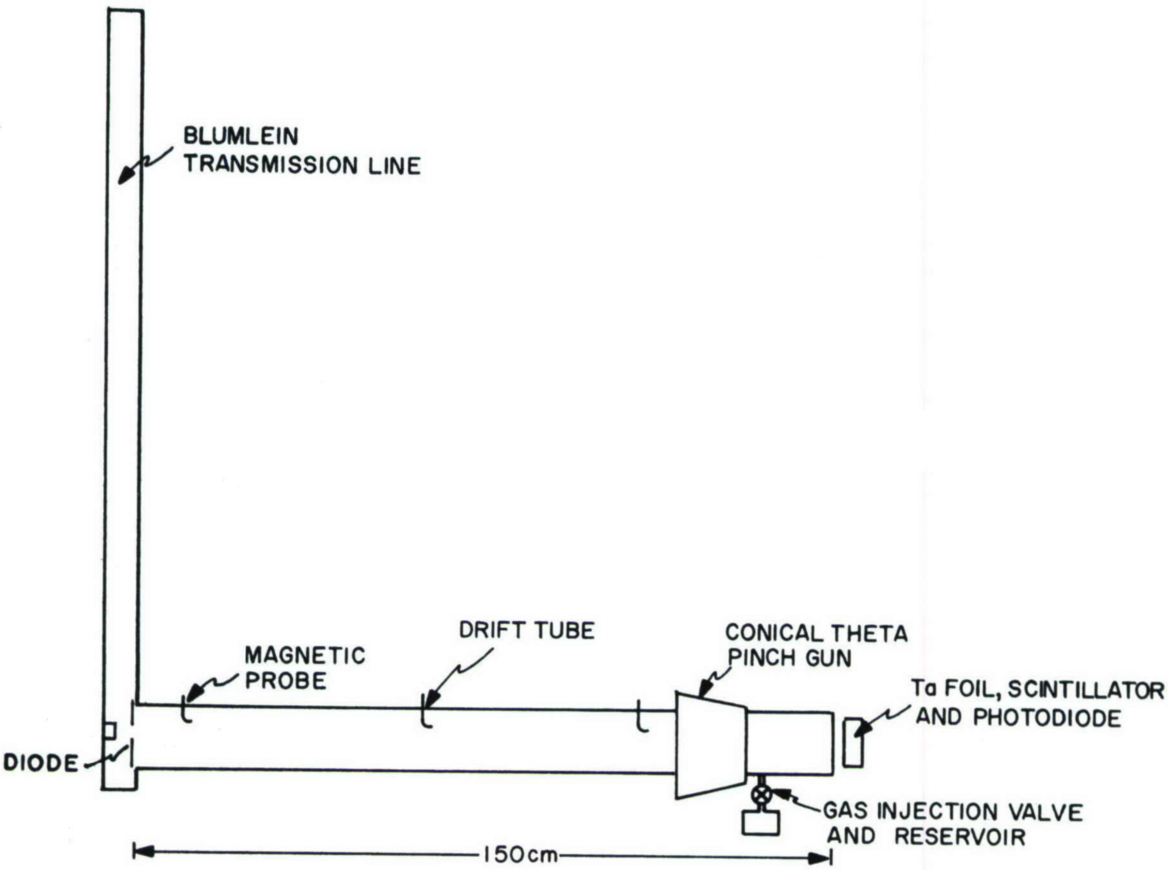

Fig. 1 - Experimental arrangement

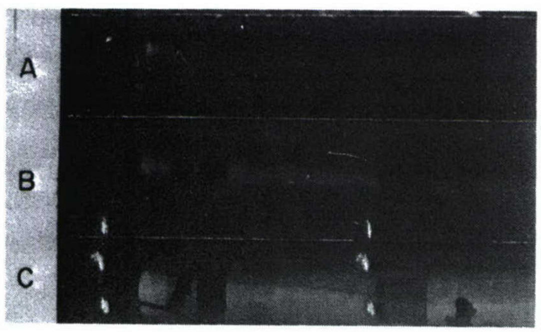

Fig. 2 - Time integrated photographs of propagation characteristics of the electron beams in vacuum, neutral gas, and plasma.

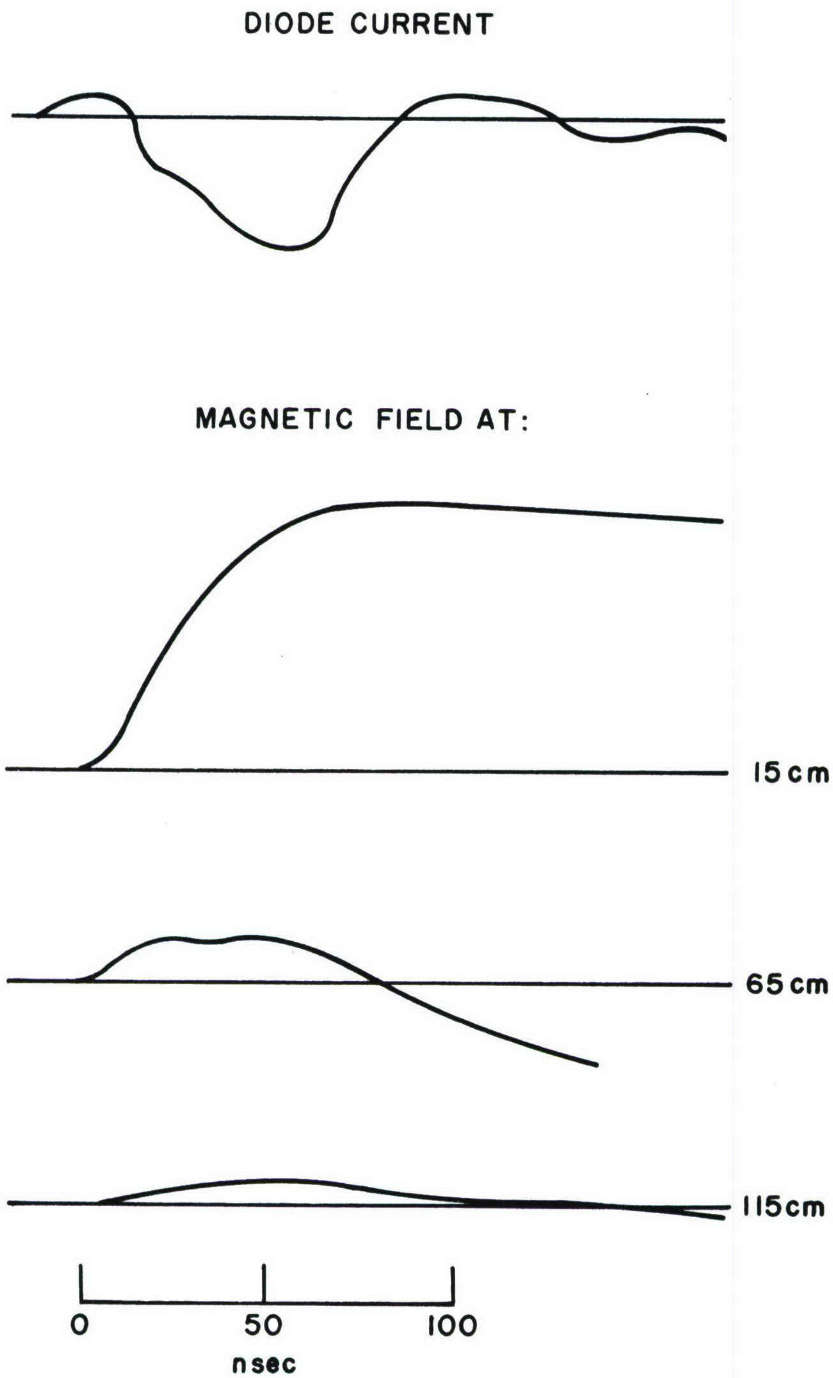

Fig. 3 — Time correlated current measurements

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13. ABSTRACT

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Counterstreaming current						